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Geo-archaeological aspects of the Modena plain (Northern Italy)

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Résumés

English Français
This paper traces the various stages of geomorphological evolution of the plain area around Modena from the VIth millennium B.C.E. (Neolithic) to the Present, through a reconstruction of the ancient landscape and human settlements.

By means of a GIS platform, geomorphological investigations led to the implementation of a Microrelief Map, a Digital Elevation Model (DEM), a Map of Surface Deposits and a Geomorphological Map.

The most striking altimetric features in the study area are the morphological changes of the Rivers Secchia and Panaro: south of Modena they run deep in the alluvial plain whereas north of the town they flow elevated over the plain.

The surface lithology consists mainly of silt, with bands of sand and clay; mainly gravel deposits crop out only near southern tracks of the main Apennine watercourses. The geomorphological landscape is mainly characterised by alluvial fans, fluvial ridges paleo-riverbeds fluvial scarps, natural springs and some depressed areas; worth of note are also forms connected with human activity.

There have been several attempts to cross–date geological and geomorphological evidence with archaeological data, on both detailed and wide territorial scales. A further advancement can now be attempted by comparing data obtained from systematic research on fluvial forms with data contained in the archives.

In the area studied, some 800 archaeological sites were identified and catalogued. Such a high number of archaeological sites can give a great deal more information than is found in any other place in northern Italy.

The research took into account the overlapping of archaeological and geomorphological data, with the implementation into a GIS (ArcGis 8.3) of geoarchaeological maps divided in main

periods and here represented from the Neolithic to the to Iron Age and from Roman period to the Early Middle Ages. The dating thus obtained for fluvial forms was mainly based on the relationship between these forms and archaeological evidence.

The upper layers of stratigraphical deposits of the urban center of Modena are quite well-known. These layers can be divided macroscopically into two large stratigraphic sequences, one belonging to the ancient Roman town of Mutina and the other to the medieval and modern town, separated by a substantial alluvial layer up to 2 meters thick in places. The archaeological strata of Modena go down to about 7-8 meters below the present surface level, reaching a depth of 11 meters in places. In this work, a three-dimensional model indicates the thicknesses of the large stratigraphic levels of the Roman Age, the alluvial deposits and the Medieval/Modern Age.

The comparison of geomorphological and archaeological data allowed many fluvial forms to be dated. In particular, the formation of some alluvial fans and ridges south and south-west of Modena took place before or during the period dating from the Neolithic to the Iron Age. The investigations have confirmed more in detail the shift to the east of the R. Secchia and to the west of the R. Panaro in the area downstream of Modena starting from the Bronze Age.

It was also possible to reconstruct the ancient soil levels in the Modena city centre starting from the Roman Age. Similarly, it was possible to measure the thickness of both archaeological stratigraphies and the various alluvial levels. Therefore, starting from the end of the Roman Age, an aggradational-type model of fluvial evolution was hypothesised for the first time thanks to this reconstruction. According to this model, the watercourses, even the minor ones, passed from a runoff occurring in deep riverbeds to one hanging over, or at least at the same level as, the surrounding plain.

The plain aggradation from the Roman Age could be ascribed to different causes, such as previously occurring processes (northbound shift of the R. Po) or coeval events (climatic changes, subsidence, deforestation, abandonment of the countryside, degradation of the water flow system set up by the Romans).

After the hydrological degradation which reached its peak at the end of the VIth century C.E., the morphological evolution of the study area in the Middle Ages and Modern times shows more stability, even if the area of Modena is still characterised by the risk of floods.

In the last centuries an important factor of geomorphological changes in the Modena plain has been human interventions.

In conclusion, in the Modena plain, as in other parts of the Po, the dominant geomorphic drivers switched from natural processes to processes strongly influenced by anthropogenetic activities.

Cet article, qui présente les résultats d'une recherche faite avec le soutien du Conseil municipal de la ville de Modène (Italie du Nord), illustre les diverses phases de l'évolution géomorphologique de la plaine de cette ville du VIème millénaire B.C.E. (Néolithique) à aujourd'hui, par une reconstitution des anciens paysages et établissements humains. (Fig. 1).

La plaine de Modène se trouve au pied de la chaîne des Apennins, qui connaît toujours une évolution géologique active. La structure complexe des Apennins se prolonge, sous les sédiments continentaux d'âge quaternaire qui constituent la plaine. Cette structure ensevelie présente deux grandes bandes de plis : les plis de l'Émilie et les plis de la Romagne (Fig. 2).

En utilisant un Système d'Information Géographique (SIG), les investigations géomorphologiques ont permis de réaliser une carte du micro-relief avec une équidistance de 1 m, un modèle numérique de terrain (DEM = Digital Elevation Model), une carte des formations superficielles et une carte géomorphologique qui prend en compte les formes de terrain naturelles et anthropiques.

Les éléments les plus caractéristiques de la région étudiée sont les changements géomorphologiques des rivières Secchia et Panaro. Au sud de Modène, elles coulent à un niveau inférieur à celui de la ville, tandis qu'au nord, elles coulent au-dessus de leur plaine alluviale (Fig. 3). Au pied des Apennins, dans le secteur sud de la zone étudiée, de nombreux cônes de déjection sont bien conservés. D'anciens dépôts alluviaux rayonnent à partir de ces cônes vers le nord et au delà de la ville de Modène. Dans cette région, on retrouve de nombreuses zones en creux qui serpentent au-dessus du niveau actuel de la plaine.

La lithologie de surface est essentiellement constituée par des limons avec quelques niveaux de sables et argiles ; elle est en corrélation avec le paléo-réseau de drainage (Fig. 4). Les dépôts alluviaux graveleux se trouvent seulement dans le secteur sud, le long des principaux cours d'eau qui descendent de l'Apennin. Leur épaisseur varie entre quelques centaines de mètres et un millier de mètres, en relation avec les structures plissées ensevelies de l'Émilie et de la Romagne. Le paysage géomorphologique est caractérisé par d'anciens cônes de déjection, d'anciens lits de cours d'eau aux chenaux anastomosés abandonnés, des rebords de terrasses et des zones déprimées où naissent des sources (Fig. 5). Les formes de terrain d'origine anthropique doivent aussi être notées.

Dans la région de Modène, l'interaction entre la géologie, la géomorphologie et l'archéologie, montre l'importance des relations entre les communautés humaines et la nature ; elle montre aussi les effets que les installations humaines ont eus sur le territoire, au moins depuis l'an 2000 avant J.C. L'étude de l'évolution des formes fluviatiles est une bonne approche pour la compréhension de l'histoire de l'occupation humaine de la plaine de Modène et plus généralement de celle du Pô.

Les travaux antérieurs ont eu pour objectif de recouper les données géologiques avec les données géomorphologiques à diverses échelles. Les travaux récents ont été conduits en comparant les données de terrain avec celles des archives. Dans la zone étudiée, 800 sites archéologiques ont été identifiés et inventoriés. Cette région est donc l'une des plus riches en information de toute l'Italie du Nord.

Toutefois, du point de vue méthodologique, une définition des relations entre les formes fluviales et les sites archéologiques ne pourrait pas être exprimée par un simple rapport de présence/absence. On doit, avant tout, faire une distinction entre les sites de surface et les sites ensevelis. Il faut ensuite prendre en compte le fait que ces deux catégories ne reflètent pas la réalité chronologique, mais plutôt les différentes vicissitudes liées aux découvertes archéologiques et à l'utilisation du terrain. Cela n'empêche pas qu'une interprétation correcte doit être fondée sur une analyse détaillée des données archéologiques afin d'établir une chronologie, la plus précise possible, et d'identifier toutes les causes naturelles ou anthropiques qui pourraient avoir déterminé cette incertitude.

Grâce au SIG (ArcGis 8.3), on a pu superposer les données archéologiques de plusieurs périodes (Néolithique, Âge du Fer, période romaine, haut Moyen Âge) aux données géomorphologiques (Fig. 6 et 7). On a ainsi réalisé des cartes géo-archéologiques qui permettent une datation des formes fluviatiles.

La partie supérieure de la stratigraphie des dépôts alluviaux de la ville de Modène est bien connue grâce à la découverte de plus de 200 pièces archéologiques. Les dépôts peuvent être divisés en deux grandes séquences stratigraphiques : l'une appartient à l'ancienne ville romaine de Mutina et l'autre à la ville médiévale et moderne. Ces deux niveaux sont séparés par une couche alluviale de 2 mètres d'épaisseur. Les couches archéologiques de l'ancienne ville de Modène sont à 7-8 mètres de profondeur (Fig. 8). Dans cet article, on propose une modélisation en trois dimensions qui indique l'épaisseur des deux niveaux archéologiques des époques romaine et médiévale/moderne et du niveau alluvial les séparant (Fig. 9).

La comparaison entre les données géomorphologiques et archéologiques a permis la datation de formes fluviatiles. Ainsi, la formation des cônes de déjection et des dépôts alluviaux les plus hauts situés au sud et au sud-ouest de Modène auraient été construits avant et pendant la période comprise entre le Néolithique et l'Âge du Fer. Ces recherches ont confirmé, avec plus de détails, que les déplacements des cours du Secchia vers l'est et du Panaro vers l'ouest, à l'aval de la ville de Modène, se sont produits, dans une région tectoniquement active et caractérisée par une intense subsidence, à l'Âge du Bronze. Il a aussi été possible de reconstituer les anciens niveaux du sol dans le centre de Modène depuis la période romaine. De même, il a été possible de mesurer l'épaisseur des couches archéologiques et des divers niveaux alluviaux. Grâce à cette reconstitution, on a élaboré pour la première fois un modèle de sédimentation fluviale depuis la fin de la période romaine. Selon ce modèle, même les plus petits cours d'eau ont modifié l'aspect de leur lit qui passe d'une forme d'incision profonde à une forme suspendue au-dessus de la plaine alluviale. Ils doivent maintenant être contenus entre des levées artificielles (Fig. 10).

La sédimentation de la plaine à partir de l'époque romaine pourrait être attribuée à des causes différentes de celles qui ont prévalu précédemment (déplacement vers le nord du Pô) ou en même temps (changements climatiques, subsidence, déforestation, abandon des campagnes, dégradation du réseau de canaux construit par les Romains). Suite au déplacement du Pô vers le nord, ses affluents descendant des Apennins ont dû allonger leur cours, ce qui a eu pour effet de diminuer leur pente et leur vitesse. La sédimentation, dans les lits fluviaux s'est donc accentuée, probablement aidée par le jeu en subsidence de la région. Pendant la période romaine, au moins 60 % du sol a été déboisé et mis en culture. Cette déforestation a facilité les processus d'érosion sur les versants et les processus de sédimentation dans les lits fluviaux. L'abandon des campagnes consécutif à une crise politique et économique à partir du IVème siècle a eu pour conséquence une accélération de ces processus d'érosion et de sédimentation. Sur l'espace urbain de Modène (la Mutina romaine), une importante sédimentation a eu lieu ; elle peut être attribuée à la dégradation des réseaux hydrauliques (canaux d'alimentation en eau et égouts) qui a suivi le désordre politico-économique.

Après la dégradation hydrologique qui atteignit son maximum à la fin du VIème siècle, l'évolution géomorphologique de la région étudiée devient plus lente au Moyen Âge et aux temps modernes, même si la zone de Modène est encore soumise au risque d'inondation. Pendant les derniers siècles, l'augmentation des activités humaines a eu pour conséquence un rétrécissement des lits fluviaux et leur approfondissement. En outre, les activités d'extraction d'alluvions le long des cours d'eau ont irrémédiablement modifié la géomorphologie locale. Dans la partie nord de la plaine, le tracé des cours d'eau a été volontairement modifié par le recoupement artificiel de méandres. Ainsi, aujourd'hui, le fonctionnement de la plaine de Modène, et plus généralement du Pô, n'est plus naturel mais fortement marqué par les activités humaines.

Entrées d'index

Index de mots-clés : archéologie, géomorphologie, Italie, Modène, plaine alluviale, SIG
Index by keywords : alluvial plain, archaeology, geomorphology, GIS, Modena

Texte intégral

I - Introduction

1 This paper aims to define the geomorphological features of the Modena plain, their evolution from the VIth millennium B.C.E. (Neolithic) to the present days, in relation to the reconstruction of the ancient landscape and human presence, pinpointing the close links between geo-environmental aspects and urban development of the town and its territory.

2 At least from the IInd millennium B.C.E., the arrangement of this territory and the extent of the population of the Modena area and, more in general, of the Po Plain, is strongly conditioned by the relationship with watercourses. The surface morphology of this part of the Po Plain results from the contribution of numerous, various and often intertwined causes: fluvial dynamics, natural subsidence, subsoil geology, earthquakes, climatic changes, fluctuations of the sea level and, especially in the more recent periods, human activity.

3 For a long length of time Man's capability to transform the environment was strongly limited by a poor technological development and low population. The prevailing farming and breeding activities were conditioned by the natural context and, in turn, conditioned it. By means of constant and gradual interventions, natural hazards were progressively reduced and natural resources more and more exploited for economic purposes. The improvement of the living conditions in the town and its surrounding territory is mainly linked to reduction of the hygienic-sanitary deterioration (produced on the environment by human settlements) and to waters control.

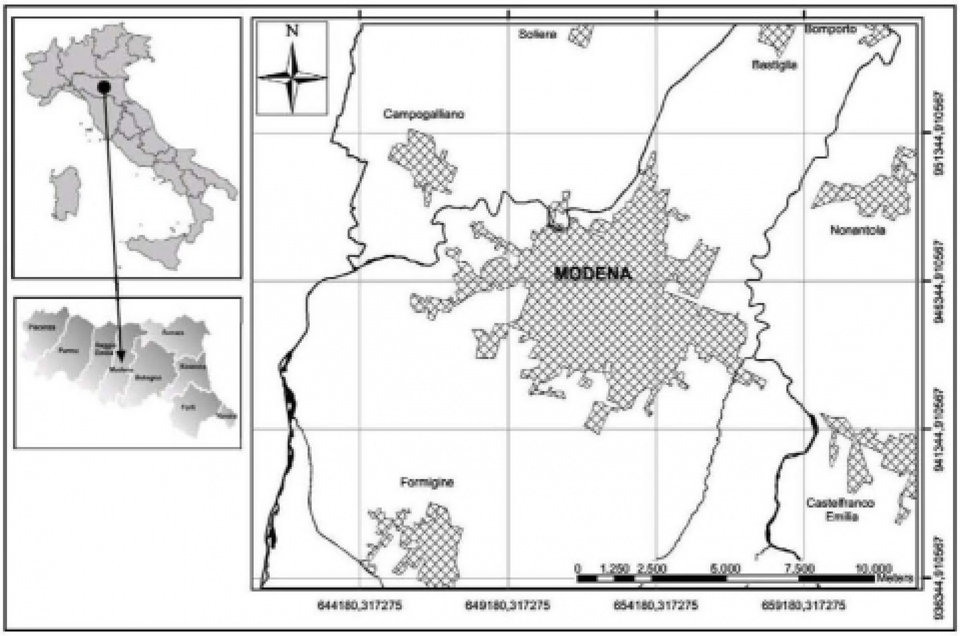
4 These interventions carried out by Man on the environment, their effects combined with natural evolutional processes, have contributed to create the present geomorphological situation.

II - Geographical, geomorphological and geological outline

5 The territory of Modena plain is located in the Emilia-Romagna Region, in the south-central sector of the Po Plain (which is the most extensive plain in Italy) (Fig. 1); the surface of the study area is approximately 200 km^2.

6 The Modena plain is situated in a temperate climatic zone (Type Cfa of Köppen's classification). From the pluviometric viewpoint the study area has an annual average rainfall of about 700 mm, with seasonal peaks concentrated in the fall and spring (about 250 mm), and minimum values in the summer (about 150 mm) (M. BOCCOLARI *et al.*, 1998).

Figure 1 - Location of the study area.



7 Two rivers flowing northward cross the Modena Plain: the River Secchia along the western sector and the River Panaro along the eastern one. The rivers Panaro and Secchia which have total lengths of 148 km and 172 km, respectively, collect waters from the central portion of the Northern Apennines and, after a course across the Po Plain (about 85 km and 90 km long, respectively), they flow into the River Po. The hydrological regime of the rivers Secchia and Panaro is characterised by two very similar peaks in the fall and in the spring and a minimum in the summer (IDROSER, 1988-a, 1988-b, 1992).

8 The Modena plain lies at the foot of the Apennine chain which is still in full evolution. At the Apennine margin the water–courses reaching the plain have built up alluvial fans which extend to the north. Since they overlap, they can be regarded as part of a continuous belt of coarse alluvial deposits spreading all along the Apennine fringe. Remains of old fans appear at the foot of the Apennine chain, and are characterised by paleosols and Pleistocene aeolian covers (loess), terraced upstream and buried downstream by the Holocene alluvia. Many ridges caused by the local evolution of ancient watercourses depart from the foot of the fans, their patterns revealing the recent migration of these rivers. The superficial alluvial deposits in the study area are Holocene in age; their particle-size distribution ranges from gravel to clay (G. GASPERI *et al.*, 1989; G.B. CASTIGLIONI *et al.*, 1997; G.B. CASTIGLIONI and G.B. PELLEGRINI, 2001).

9 The plain/Apennines boundary is purely morphological as the Apennine structures continue towards NNE as far as the Po River (about 30 km north of the study area) buried under the Quaternary continental sediments; fault or fold deformations also involve these deposits (M. PELLEGRINI *et al.*, 1976; G. DI DIO, 1998).

10 According to subsurface geological data (M. PIERI and G. GROPPI, 1981), under the Modena plain the buried Apennine structures are arranged in two large folds and thrusts belts: the Emilia Folds and the Romagna Folds (Fig. 2).

Figure 2 - Subsoil geological structures of the Modena plain.

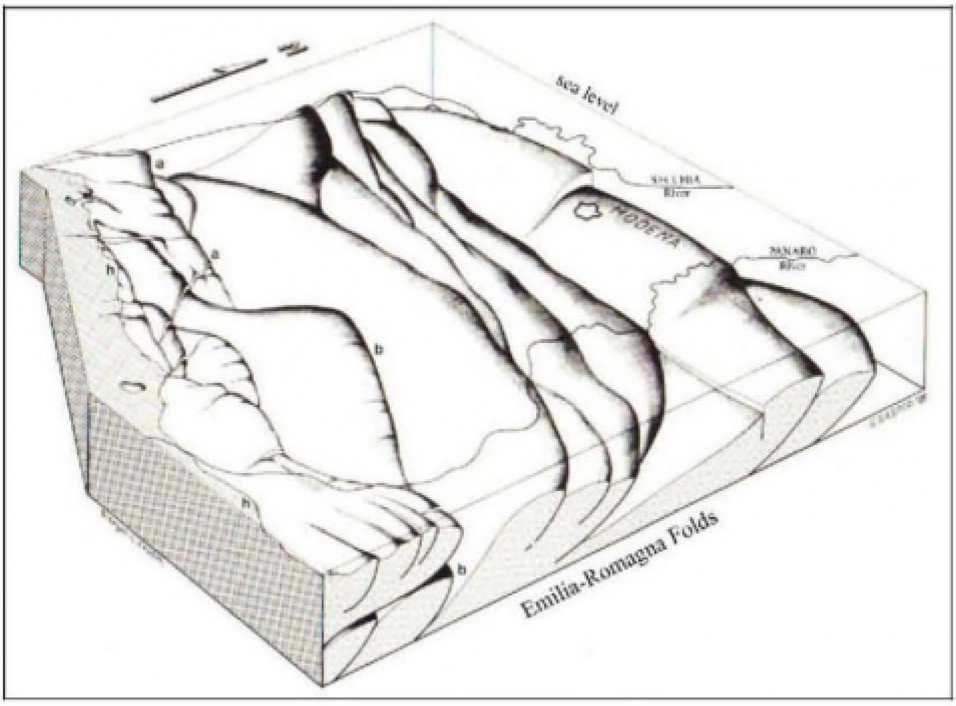


Figure shows the schematic trend of the top of the Plio-Pleistocene alluvial sediments (according to G. GASPERI *et al.*, 1989).

III - Geomorphological investigations

11 As concerns geomorphological investigations, in this study the data were primarily collected by means of bibliographic research, aerial photo interpretation and field survey.

12 In a second phase, all these data were introduced into a GIS (ILWIS 2.2 and ArcGis 8.3) and organised in different georeferenced thematic maps (Digital Elevation Model, Surface Deposits and Geomorphological Map) with a linked database. All maps were elaborated at a 1:25,000 scale.

1) Altimetric study (Microrelief Map and Digital Elevation Model)

13 The topographic maps of the study area are from the last edition (1988) of the Emilia-Romagna Technical Regional Map (CTR), at the 1:25,000 scale. The format of these maps is a digital one; therefore the raster edition was assembled, imported and georeferenced in ILWIS.

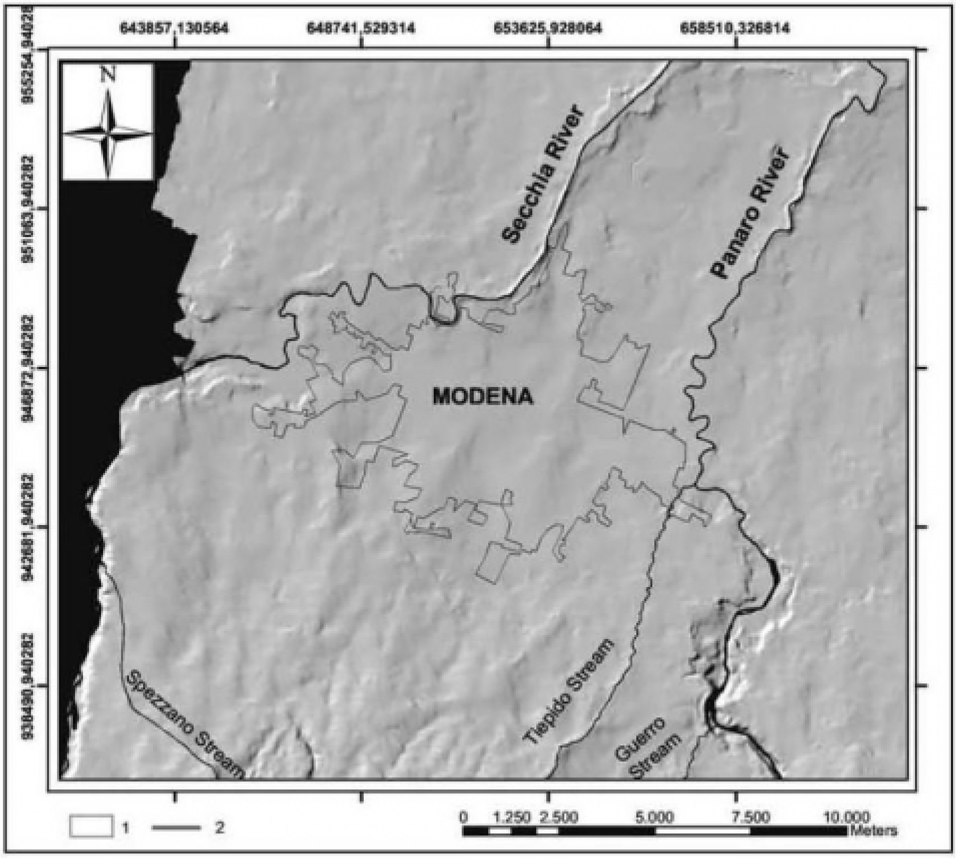
14 The microrelief map of the territory was prepared by a hand-made geometric method. The microrelief map was realised using 1 m contour intervals. Automated treatment of the isolated elevation data would not produce a realistic model, representative of the natural topographic surface. This is due to the heavy conditioning of human activities in the scattered points. Any interpolator is able to solve situations where the variables are homogeneous in space and time and are not influenced by human conditioning. The hand-made microrelief map was prepared considering only the elevation points in natural conditions or introducing an evaluation of their naturalness. The areas affected by infrastructures, such bridges, embankments, quarries, *etc.*, were discarded. Contour lines represent the natural topographic relief without influence from human changes.

15 Afterwards, the contour lines were digitalized and the obtained segment map was rasterised and interpolated in order to obtain a Digital Elevations Model (DEM) (C. GIUSTI, 2001).

16 In the study area, the difference in elevation is between 102 m and 22 m a.s.l., the slope decreasing from SSW towards NNE; the city of Modena is located at about 35 m a.s.l.

17 By examining the microrelief map and the DEM (Fig. 3), a change of inclination can be noticed at the southern boundary of Modena (indeed, the inclination of the ground level changes from 1.2 % to 0.8 %). Nevertheless, the most striking features in this area are the morphological changes of the Rivers Secchia and Panaro: south of Modena they run deep in the alluvial plain whereas north of the town they flow elevated over the plain.

Figure 3 - Digital Elevation Model of the Modena plain.



1: Boundary of the city of Modena. 2: Main water courses.

18 In the southern portion of the study area the numerous alluvial fans formed at the foot of the Apennines are quite evident. From those, fluvial ridges stretch out which continue as far as the northern part of the Modena valley and beyond. In the northern portion of the study area, various altimetrically depressed areas can be recognised between one fluvial ridge and the next.

2) Surface deposits

19 The Modena plain is made up of alluvial deposits from the Rivers Secchia and Panaro and their tributaries, and vary in grain size from gravel to clay; their thickness is variable from hundreds of meters to one thousand meters in relation with the depth of the Emilia and Romagna Folds.

20 A Map of Surface Deposits (Fig. 4) was elaborated on the basis of field samples and bibliographic data (R. GELMINI et al., 1988; R. GASPERI et al., 1989). The surface deposit data taken from literature were digitalized and imported into an ILWIS in different layers. Through the overlap of these layers, incongruent areas were identified and a detailed field survey was carried out in them. Lithological samples, taken with a hand drill at a depth between 0,5 and 1 m from the topographic surface, were defined directly in the field as particle size classes, using the technique of the harmonic thread (G. GASPERI and R. GELMINI, 1976). Many of them have been tested in laboratory

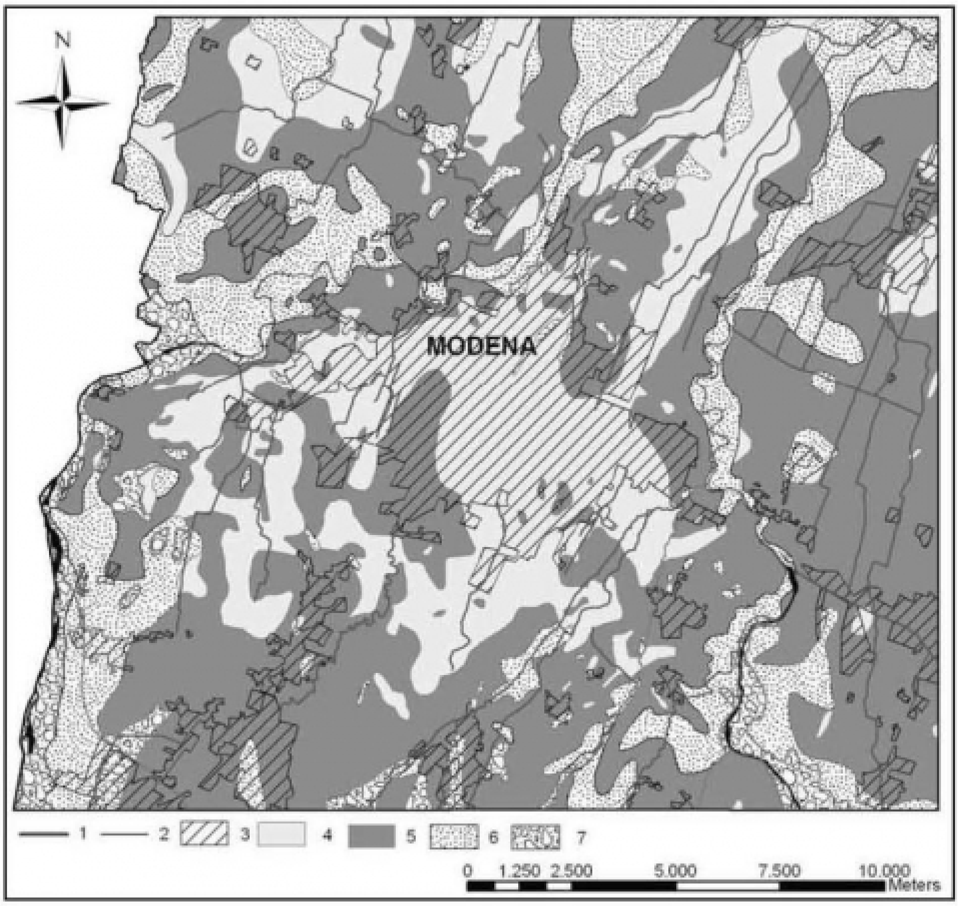
with particle-size analysis. The locations of the field samples were introduced in the GIS as a lithological point map and the results of sample analysis were introduced into the database as attribute tables. On the basis of these data, a polygon map of the surface deposits was created and classified in four classes: mainly gravel, mainly sand, mainly silt and mainly clay.

21 The surface lithology consists mainly of silt, with bands of sand and clay mostly SSW-NNE oriented. It is correlated to the paleo-drainage network. Mainly gravel deposits crop out only in the southern sector near the tracks of the Rivers Secchia and Panaro and of the main Apennine watercourses.

3) Geomorphology

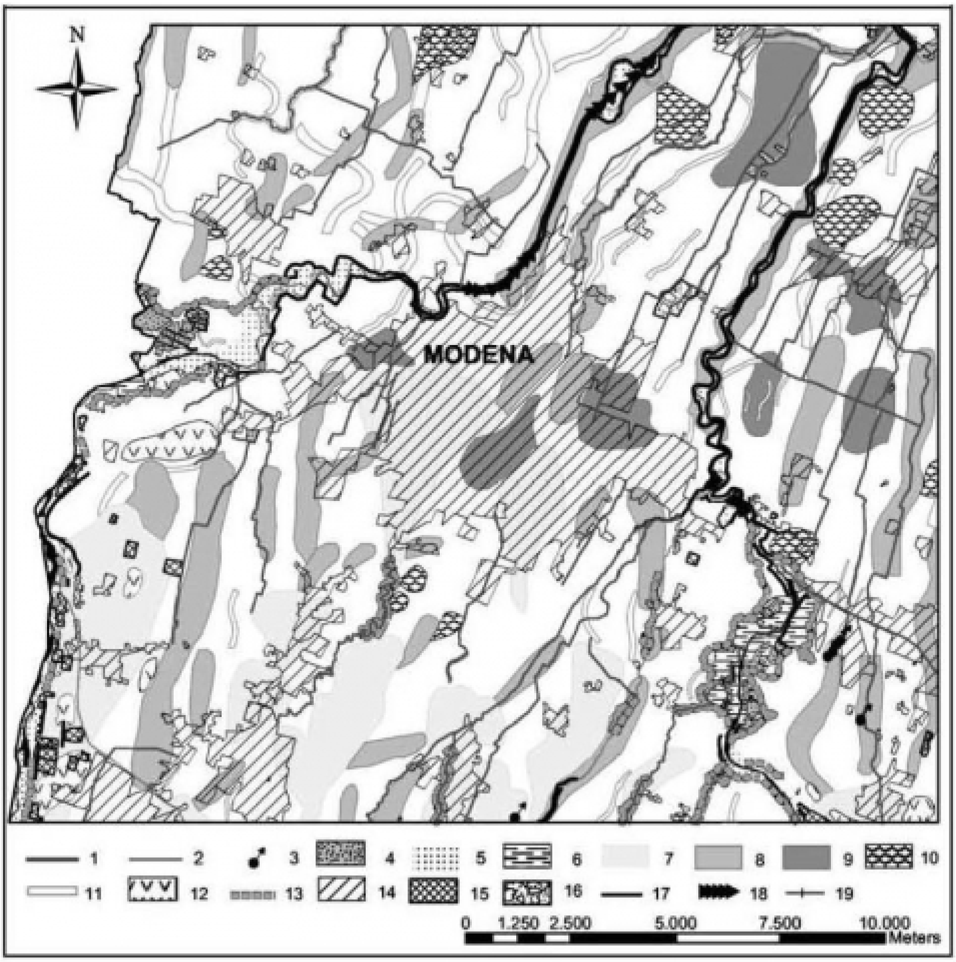
22 The geomorphological characteristics of the study area are mainly the result of the evolution of the Rivers Secchia and Panaro and of human activity. The geomorphological information was obtained from field survey, aerial photo-interpretation and bibliographic research and from the analysis of other maps (Micro-relief Map, DEM and Map of Surface Deposits). The geomorphological elements, both natural and man–made landforms, were divided into three different maps (point, segments and polygon map) and overlapped for the implementation of the Geomorphological Map (Fig. 5). In this document, new features which are not indicated in the Geomorphological Map of the Po Plain (G.B. CASTIGLIONI *et al.*, 1997) were mapped.

Figure 4 - Map of the Surface Deposits of the Modena Plain.



1: River. 2: Secondary stream. 3: Built-up area. 4: Mainly clay. 5: Mainly silt. 6: Mainly sand. 7: Mainly gravel.

Figure 5 - Geomorphological Map of the Modena Plain.



1: river. 2: secondary stream. 3: spring area. 4: pond. 5: high-water bed. 6: flow regulation systems. 7: alluvial fan. 8: fluvial ridge. 9: depression. 10: crevasse splay. 11: paleoriver at the plain level. 12: area with traces of abandoned braided streams. 13: fluvial scarp. 14: built-up area. 15: quarry. 16: waste. 17: artificial embankment. 18: artificial meander cut-off. 19: main fluvial barrage.

23 The geomorphological landscape is mainly characterised by alluvial fans and paleo-riverbeds (at plain level as well as fluvial ridges and traces of abandoned braided streams). They testify the transition in the plain from a braided system, in the southern sector, to a meander pattern, in the northern sector. Other important geomorphological features in the southern sector are the fluvial scarps near the Rivers Secchia and Panaro, and their main tributaries. The fluvial ridges, one to two meters high, are parallel to water courses in a SSW-NNE mean direction. In the northern sector some depressed areas are also in evidence. Fluvial ridges and depressed areas have a great importance both in recognising the geomorphological evolution of the area and in assessing flood hazard. In fact, the knowledge of these morphological characteristics of the plain permits both the confining of foods (fluvial ridges, flank) and the flooded area (depressed areas) to be assessed. Geomorphological data contain also forms connected with human activity such as quarries, built-up areas, artificial embankments, meander cut–offs and flow regulation systems. In detail, in the southern sector in the XXth century the increase of man's interventions along rivers (construction of embankments, walls and groynes) in order to protect the territory from floods and reclaim high-water areas for farming practices, led to a narrowing of the riverbeds in several points. In the past 40 years, the riverbeds have been subject to considerable deepening, which has reached up to 10 m in the main watercourses. This dramatic change was due to gravel excavation activitiesalong riverbeds and the construction of fluvial barrages (D. CASTALDINI and P. BALOCCHI, 2006).

24 Downstream of the city of Modena, the drainage network has been strongly influenced by artificial embankment which confines the rivers in narrow beds. The courses of the Rivers Secchia and Panaro were conditioned by artificial meander cut-offs carried out since the XIXth century to reduce flood hazard. Since these cut-offs did not reduce adequately flood hazard, flow regulation systems (consisting of basins for storage of flood waters) were constructed east and west of Modena along both rivers.

Minor watercourses are completely canalised: the canal network in the northern sector was created by the Romans in the IInd century B.C.E.

IV - Interaction between geomorphology and archaeology

25 The interaction between geomorphology and archaeology in the Modena territory shows the significance of the relationship between human communities and Nature. It also shows the effect these communities had on the territory from 2000 B.C.E. onwards.

26 The evolution of river forms is one of the main keys for understanding the history of human settlements in the Modena area and in the plain area generally. There have been several attempts to cross-date geological and geomorphological evidence with archaeological data, on both detailed and wide territorial scales (M CREMASCHI and G. GASPERI, 1988; M CREMASCHI and G. GASPERI, 1989; G. GASPERI *et al.*, 1989; A. CARDARELLI and M. CATTANI, 1994; S. PELLEGRINI, 1999; A. CARDARELLI *et al.*, 2000; S. LUGLI *et al.*, 2002; S. LUGLI *et al.*, 2004). A further advancement can now be attempted by comparing data obtained from systematic research on fluvial forms, as shown in geomorphological maps, with data contained in the archives set up since 1983 by the Museo Archeologico Etnologico of Modena and the Soprintendenza ai Beni Archeologici of the Emilia-Romagna Region, regarding archaeological settlements. In the area studied, some 800 archaeological sites were identified and integrated into the "Archaeological map of the Municipality of Modena" (A. CARDARELLI and M. CATTANI, 2000).

27 Such a high number of archaeological sites – distributed between the Neolithic and the Early Middle Ages (6000 B.C.E. to Xth century C.E.) – can give a great deal more information than is found in any other place in northern Italy. Thanks to all these data, it is possible to attempt a dating of the complex situation concerning the fluvial forms represented on geomorphological maps.

28 From a methodological standpoint, though, a definition of the relationship between fluvial forms and archaeological sites cannot be expressed by a simple presence/absence ratio. The presence of archaeological findings overlapping landforms identifies, as a rule, an ante quem dating, whereas an opposite relation – that is a landform overlapping buried archaeological findings – is identifiable with a post quem dating. First of all, it is therefore necessary to distinguish between sites identified on the soil surface and buried ones. However, it is difficult to compare these two categories: the percentage of buried sites, for example, is considerable in the urban area, where findings of Roman Age can be discovered several meters below the present ground surface whereas in the countryside buried sites from the same epoch are much rarer. Obviously, this does not reflect archaeological reality but rather various vicissitudes linked to archaeological remains and land-use. The centuries-long human development in urban areas has left a large number of subsoil archaeological remains, starting from those recorded in Medieval and Renaissance chronicles, whilst in the countryside archaeological discoveries have mainly been made thanks to ploughing activity. The latter has brought to light ancient remains buried within one meter in depth. Evidence of this situation is clearly shown in the areas immediately south and north of Modena, where archaeological findings of Roman Age are extremely rare compared to adjacent areas. In this case, the evidence produced by the city centre and the identification of the inundation fan, which in late Antiquity-Early Middle Ages contributed primarily to the burial of the Roman town, suggests that this gap may be ascribed to the burial of archaeological evidence by that flood. In other words, this gap is not real but only apparent. Indeed, if we had the opportunity to know all the buried evidence in the study area, we would probably have a picture quite similar to that of the areas with superficial remains. The only difference would be that the archaeological remains would be much better preserved, not having undergone the degradational processes caused by prolonged farming activities. Furthermore, there are also controversial data which

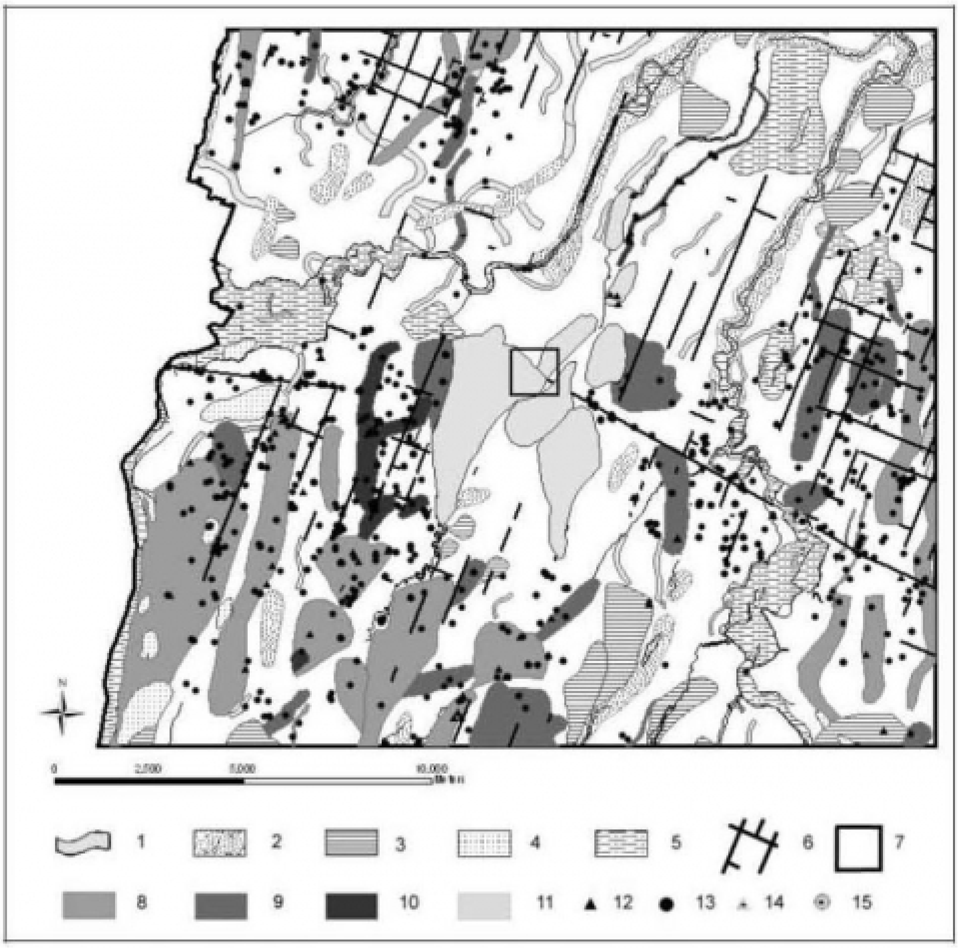
hinder clear interpretation of these archaeological discoveries. For example, in certain cases superficial findings have been identified next to buried ones within small areas: but they are all ascribable to the same chronological macrobelt. In this case, their correct interpretation must rely on a careful analysis of archaeological data in order to establish chronology as precisely as possible, and identify any natural or artificial causes which might have determined this uncertainty. At a macroscopic level, a similar condition could be found within the urban area, where several buried remains dating from the Cathedral construction period can be found. In this case a geomorphological explanation can be provided (the area of the Cathedral is topographically higher than the level of the late-ancient-early medieval town) and, also a historical one since the Cathedral has survived practically unchanged up to our times because of its religious, social and symbolic meaning. Other kinds of coeval evidence have undergone demolition, alteration and various superimpositions.

29 This research took into account the overlapping of archaeological and geomorphological data, with the implementation into a GIS (ArcGis 8.3) of geo-archaeological maps subdivided into main epochs (here represented in two maps: from the Neolithic to the to Iron Age (Fig. 6); from Roman period to the Early Middle Ages (Fig. 7)). The dating thus obtained for fluvial forms was mainly based on the relationship between these forms and archaeological evidence.

Figure 6 - Geoarchaeological map of the Modena Plain with fluvial forms dating from the Neolithic to the Iron Age.

1: paleoriver at the plain level. 2: fluvial ridge. 3: alluvial fan and crevasse splay. 4: area with traces of abandoned braided streams. 5: depression. 6: location of Mutina (Modena roman town). 7: Neolithic and Bronze Age fluvial form. 8: Iron Age fluvial form. 9: surface Neolithic and Bronze Age site. 10: surface Iron Age site. 11: buried Neolithic and Bronze Age site. 12: buried Iron Age site.

Figure 7 - Geoarchaeological map of the Modena Plain with fluvial forms dating from the Roman period to the Early Middle Ages.



1: paleoriver at the plain level. 2: fluvial ridge. 3: alluvial fan and crevasse splay. 4: area with traces of abandoned braided streams. 5: Depression. 6: centuriation. 7: boundary of Mutina (Modena roman town). 8: Neolithic and Bronze Ages fluvial form. 9: Iron Age fluvial form. 10: Roman fluvial form. 11: Early Middle Ages fluvial form. 12: surface Roman site. 13: surface Early Middle Ages site. 14: buried Roman site. 15: buried Early Middle Ages site.

30 Therefore, if, for example, a fluvial ridge had a buried Neolithic site and evidence of the Bronze Age at the surface, its dating was considered subsequent to Neolithic times and prior to or coeval with the Bronze Age. If we consider anteriority and/or contemporaneity, the relation between fluvial forms and archaeological remains is more ambiguous than the relation shown by fluvial forms overlapping archaeological evidence. The location of a site on top of a ridge or near to a paleoriverbed may be subsequent to the complete formation or extinction of these features. Or it may also indicate that the feature's formation phase is contemporary to a river's sedimentation activity. For example, in the case of the *terramara* villages from the Bronze Age, a recent hypothesis assumes that their frequent association with fluvial ridges or paleoriverbeds dates from a period when the watercourse was already in a senescence phase, or even extinct (C. BALISTA, 2003).

31 As for dating fluvial forms, sometimes data from sites outside the study area have been taken into account, as they allow a precise chronological reference. For example, paleoriverbeds which continue outside the study area were seen to be clearly related to archaeological sites, thus allowing even the stretch with no archaeological evidence to be dated.

32 In the area studied, findings from these phases are differentiated according to their entity and the level of our knowledge. Neolithic remains (6000 to 4000 B.C.E.) are extremely rare and sporadic in the Modena territory. Instead, south of the study area, the sites of Fiorano (early Neolithic) and Pescale (from the early to the late Neolithic, with subsequent documentary evidence in the Copper and Bronze Ages) are the best-known. Some alluvial fans and ridges south and south-west of Modena show superficial remains which are generally thought to date from the Neolithic; it can therefore be assumed that the formation of these features took place before or during that period (Fig. 6). The Copper Age, or Eneolithic is poorly represented, with very few findings ascribable to the latest period (Bell Beaker facies). The formation of the westernmost

fan can presumably be ascribed to the Copper Age (3300 to 2300 B.C.E.) thanks to the finding of surface remains belonging to that period. Later, this alluvial fan hosted some terramare on its surface (M. CATTANI and D. LABATE, 1997).

33 A ridge south-west of Modena and a series of other fluvial forms (paleoriverbeds and ridges) east and north of the town are ascribable to a phase immediately preceding or coeval with the middle and recent Bronze Age (1600 to 1200 B.C.E.) owing to the presence of buried Neolithic findings or the clear relation between ridges and Bronze Age sites found at the surface. Particularly interesting is the identification of an ancient bed of the river Panaro – recognised thanks to the identification of fluvial ridges east of Modena – which hosted the *terramare* of Gaggio and Redù (A. CARDARELLI et al., 2003). This evidence confirmed the close link between watercourses and settlements, as recognised also in other areas (M. CREMASCHI, 1997, 2000; A. CARDARELLI *et al.*, 2003).

34 Our knowledge about the Iron Age is limited and this makes the chronological attribution of geomorphological evidence and, in particular, fluvial forms rather difficult (Fig. 6). In particular, as regards the period immediately following the end of the *terramare* period (final Bronze Age, XIIth - early Xth centuries B.C.E.), archaeological data from the study area are not available. The situation in the early Iron Age (end of Xth to VIIIth centuries B.C.E.) is just as problematic: the only sure evidence regards a dwelling site in Cognento, SW of Modena (M. PACCIARELLI, 1988). Therefore, chronological classification of these sites has relied on the presence of sites from the second Iron Age (VIIth to VIth centuries B.C.E.), which are relatively more frequent, and which are found at the surface on top of or next to various fluvial forms. These findings seem to be earlier than the geomorphological forms and cannot be ascribed with certainty to a period preceding the final Bronze Age.

35 In this phase of the Iron Age, settlements seem to have followed a capillary-type development linked to agricultural activities with several farmsteads and canal networks (M. CATTANI, 1994). The presence of an urban centre (Mutina?) can therefore be assumed but it is a well-known fact that the Etruscan town which later became the Roman colony of Mutina can only be inferred on the basis of historical sources, as there is no archaeological evidence. Nevertheless, two sites corresponding to fortified villages occupying a surface of about one hectare, have been identified to the east of Panaro river near Nonantola and Castelfranco Emilia. They bear witness to the fact that during the Vth century B.C.E. there were also other settlements smaller than towns but larger than farmsteads (L. MALNATI, 1988; V. KRUTA and L. MALNATI, 1995; V. KRUTA and N. GIORDANI, 1996; L. MALNATI, 2003).

36 The presence at the surface of archaeological findings from the second Iron Age, and the contextual lack of surface sites in the same areas from the period between the Neolithic and the recent Bronze Age, allow some fluvial forms to be attributed to a period of the XIIth to VIthVth centuries B.C.E.

37 On the other hand, fluvial forms showing remains from the Roman Age at the surface have been dated to a generic pre-Roman Age since they lack surface or buried findings ascribable to the Iron Age. Actually, they could have formed at any time prior to the surface evidence, even in a phase of the Roman Age just preceded the age of the sites investigated. Nevertheless, at the present state of the art, it is not possible to further define these chronological details.

38 The Roman Age (IInd century B.C.E. to IVth century C.E.) is represented by a large number of archaeological findings, which – besides the urban core of the city of Mutina – have been confirmed by numerous pieces of evidence, such as farms, villas, necropoles, road infrastructures and traces of the centuriation system. This system, which was made up of considerable, efficiently managed drainage works and canals, gave a systematic and rational arrangement to the whole area and was one of the components which provided the territory with a certain degree of stability, also from the hydrological viewpoint. Compared with previous periods, the fluvial forms datable to the Roman Age are fewer, whereas the centuriation traces are still evident. This shows how even watercourses were subject to the systematic control and management of a well-organised territory, although in places they have been obliterated by subsequent alluvial deposits (Fig. 7).

39 In order to date fluvial forms to the Roman Age, findings showing buried evidence from the Iron Age and Roman sites at the surface were selected.

40 North of the Via Aemilia a stretch of paleoriverbed is flanked by some Roman sites and could therefore owe its origin to this period. Nevertheless, one should bear in mind that the surrounding area lacks traces of Roman settlements, nor is the centuriation pattern recognisable here. In addition, numerous records from the Middle Ages have been identified on the same paleoriverbed stretch and, in one case, even on a Roman site. Therefore it cannot be excluded that Roman findings could be evidence of reuse of ancient artefacts (in particular bricks) in the medieval age.

41 On the right-hand side of the River Panaro a paleoriver stretch could be ascribed to the Roman Age owing to the surface presence of three sites. As regards the course of the River Panaro, it is interesting to note that from the Bronze to the Roman Age a series of its paleoriverbeds shifted progressively westwards.

42 The Roman evidence in the city of Mutina is all buried by thick alluvial deposits which preserved the Roman town excellently, as confirmed by the numerous, although punctiform, findings recovered from the urban area. The dating of these events to an epoch of late Antiquity is widely documented by numerous findings, in particular burial artefacts. A sarcophagus discovered in 1987 in the heart of the historical centre was covered by alluvial deposits. The items recovered from inside the sarcophagus can be ascribed to an early period of the Longobard era, that is around the last quarter of the VIth century. Another Longobard tomb can be ascribed to the same chronological period, but with a slightly more recent dating than the site previously quoted (S. GELICHI, 1988): it is located on top of the alluvial layer. It can therefore be inferred that at least one of the alluvial events which characterised the post-Roman stratigraphy of the Modena subsoil can be ascribed to a date around the end of the VIth century. This coincides with the well-known historical source of Paulus Diaconus on the dramatic hydrogeological disarray processes which affected northern Italy around the year 590. Recently, the alluvial deposits of the Modena subsoil have been analysed and prevalently linked to sediments from the stream Cerca, a watercourse that used to pass by or flow through the city in Roman times (S. LUGLI *et al.*, 2004).

43 A series of fluvial forms in urban areas which also affect areas both north and south of the city, can be attributed to late Antiquity or early Middle Ages (Fig. 7).

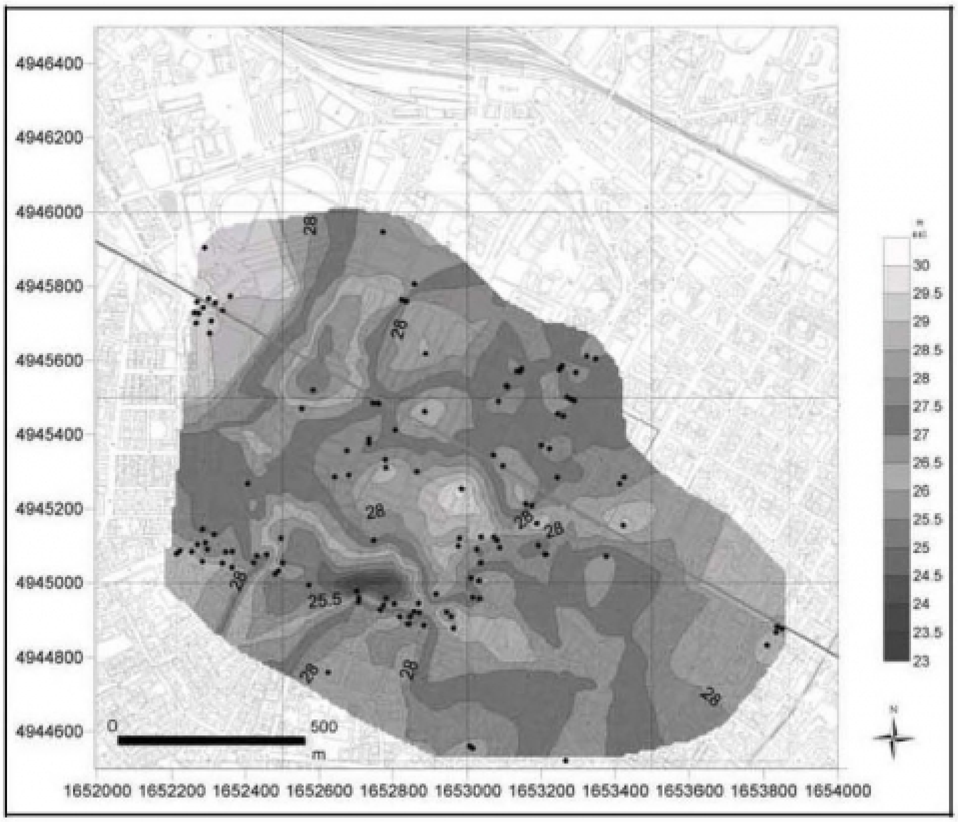
44 The impact of hydrogeological disarray on the city of Mutina and on the surrounding territory is shown by the thickness of the alluvial layers, which are over two meters thick in some parts of the town. This is confirmed also in the areas immediately to the north and south of the city centre where remains from the Roman Age are buried and have largely been obliterated by centuriation.

45 In particular, an inundation fan to the south of the city has a series of buried Iron and Roman Age settlements in its upper part, which seem to indicate its breach point.

46 The top layers of earth beneath the city of Modena are quite well-known, thanks to the almost 200 archaeological finds brought to light. These layers can be divided macroscopically into two large stratigraphic sequences, one belonging to the ancient Roman town of Mutina and the other to the medieval and modern town. The two sequences are separated by a substantial alluvial layer up to 2 meters thick in places, which was deposited at the end of the VIth century C.E. (M. CREMASCHI and G. GASPERI, 1988; S. GELICHI and N. GIORDANI, 1994).

47 The archaeological strata of Modena go down to about 7-8 meters below the present surface level, reaching a depth of 11 meters in places (Fig. 8).

Figure 8 - Altimetrical reconstruction of the Roman-age ground surface of Mutina (IInd-Ist centuries B.C.E.).

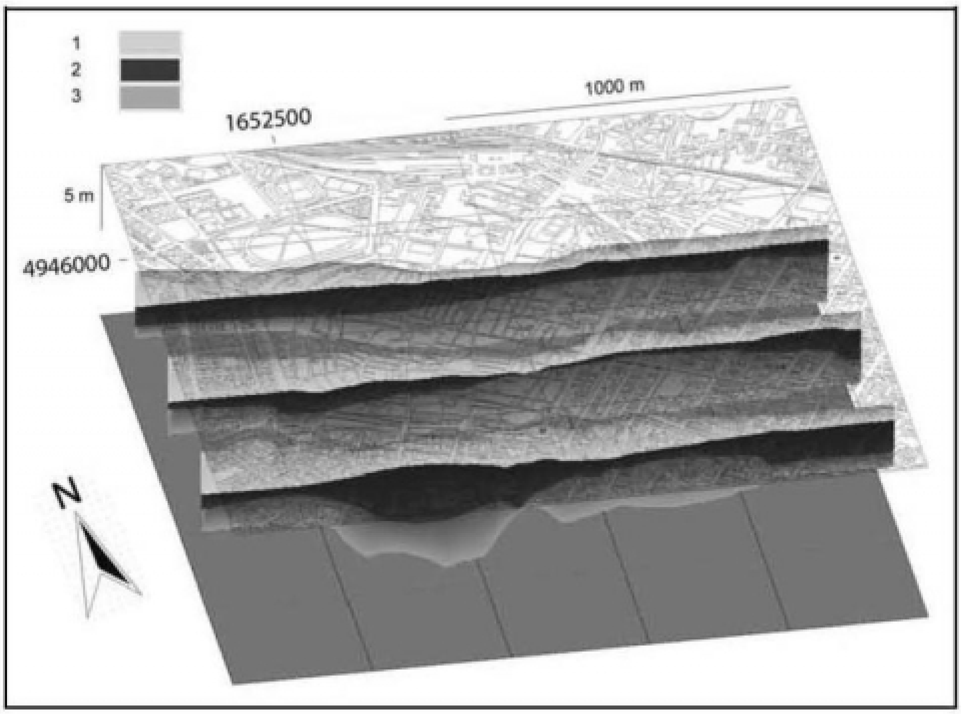


Black dots show evidence ascribable to the Roman soil level. Grey shades show the isobaths with 0.5 m equidistance. The deepest isobaths are represented by the darkest shades. UTM coordinates.

48 The medieval and modern layers are on average 2 meters deep. Below them there are the alluvial layers at a depth between 3.5 and 4 meters. Further down are found the layers from late-Antiquity and the Roman Age. A more detailed analysis of these strata shows that there are marked differences between one area of the city and another. For example, the depth of the base of the alluvial layers is only 2-2.5 meters in the vicinity of the Cathedral whilst in the areas south of the historical centre it is over 9 meters.

49 A. CARDARELLI *et al.* (2000) reconstructed the altimetry of some ancient surfaces of the Modena city and the thickness of some macrostratigraphic levels by using "Surfer" software. In particular, the numerous data on the archaeological map of the city were used, together with the archaeological interpretation of data from mechanical borings, surveys and cone penetration tests, to make a reconstruction of the city's altimetric levels in Roman times, during late Antiquity and above the alluvial layers. At the same time, it was possible to indicate the thicknesses of the large stratigraphic levels of the Roman Age, the alluvial deposits and the medieval/modern age. The work presented here has envisioned also the use of different stratigraphic analysis software – known as "Rockworks 2002" – utilising a three-dimensional model which should provide sections and profiles as well as allowing the reconstruction of altimetric levels (Fig. 9).

Figure 9 - Map of Modena Town with three east-west sections of the reconstructed archaeological macrostratigraphy.



The 3D model includes the thickness of the following units: 1: Medieval layers; 2: alluvial deposits; 3: Roman layers. UTM coordinates.

V - Conclusion

50 In this work the comparison of geomorphological and archaeological data allowed many fluvial forms to be dated and the stages of geomorphological evolution of the plain around Modena from the VIth millennium B.C.E. (Neolithic) to the Present, to be traced.

51 In particular, the formation of some alluvial fans and ridges south and south-west of Modena took place before or during the period dating from the Neolithic to the Iron Age.

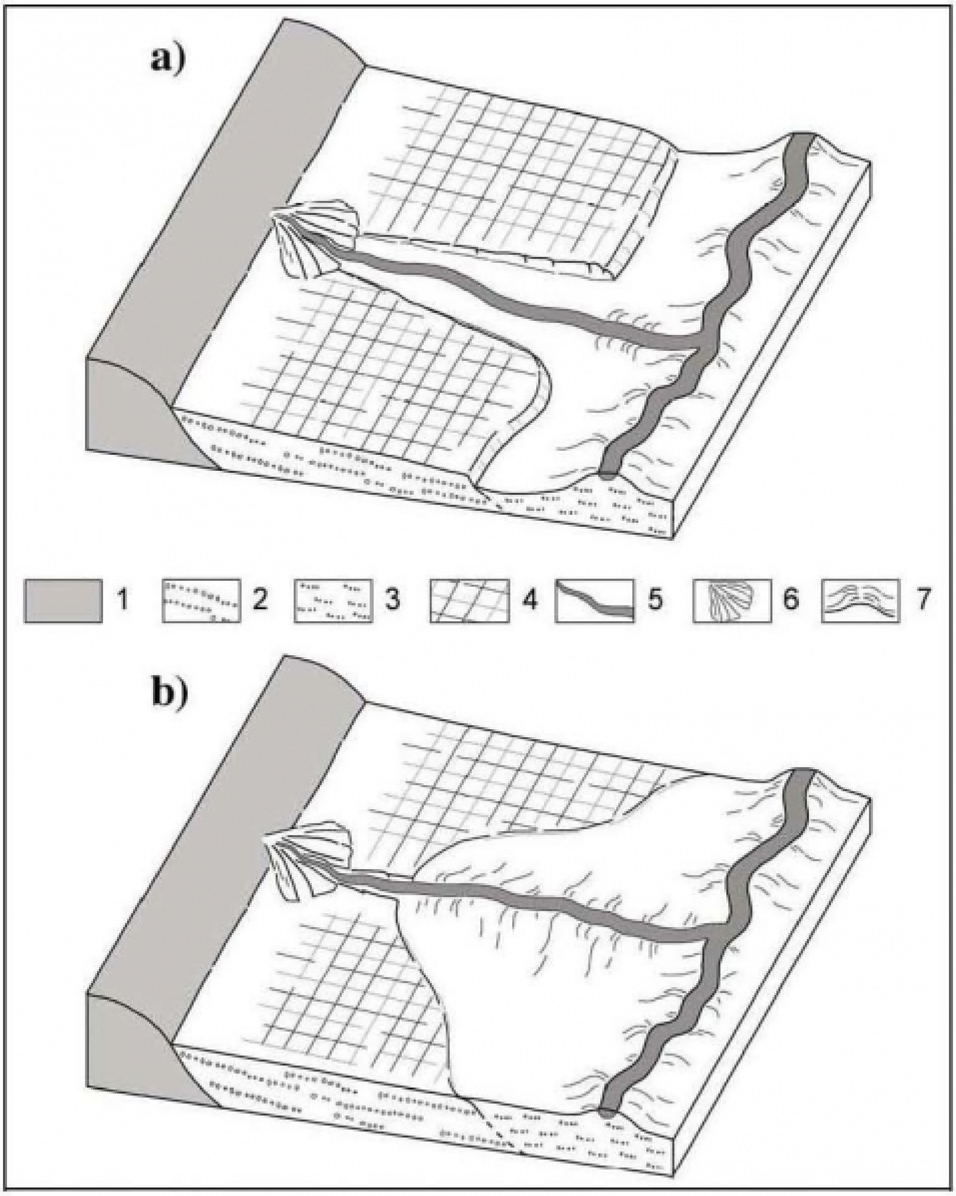
52 The geomorphological and archaeological investigations have confirmed more in detail the shift to the east of the R. Secchia and to the west of the R. Panaro in the area downstream of Modena, which is a tectonically depressed area characterised by intense subsidence, starting from the Bronze Age (M. PANIZZA, 1975; C. BARTOLINI *et al.*, 1982; D. CASTALDINI *et al.*, 1988). In the Po Plain natural subsidence varies from area to area (among the most recent papers, cf. G.B. CASTIGLIONI *et al.*, 1997; E. CARMINATI and G. DI DONATO, 1999; G.B. CASTIGLIONI and G.B. PELLEGRINI, 2001; E. CARMINATI and G. MARTINELLI, 2002). The speed of movements due to natural processes is generally quite slight (less than 0.3 mm/year) in the plain belts near the Apennines and the Alps whereas it is particularly high in some specific areas (e.g., in the Po Delta it is more than 2 mm/year). According to E. CARMINATI and G. MARTINELLI (2002), in the area downstream of Modena the average rate of geological subsidence is higher than 1 mm/year.

53 The assumption that the Rivers Secchia and Panaro started to converge in the area north of the city only in rather recent times is supported also by detailed sedimentological investigations (S. LUGLI *et al.*, 2004).

54 Furthermore, it was also possible to reconstruct the ancient soil levels in the Modena city centre starting from the Roman Age. Similarly, it was possible to measure the thickness of both archaeological stratigraphies and the various alluvial levels.

55 Therefore, starting from the end of the Roman Age, an aggradational-type model of fluvial evolution was hypothesised for the first time thanks to this reconstruction. According to this model, the watercourses, even the minor ones, passed from a runoff occurring in deep riverbeds to one elevated with respect to, or at least at the same level as, the surrounding plain within artificial embankments (Fig. 10).

Figure 10 - Schematic illustration of the evolution of the study area.



a: Roman Age. b: present. 1: Apenninic margin. 2: pre-Roman alluvional plain. 3: Roman and post-Roman alluvional plain. 4: Roman centuriation system. 5: River. 6: alluvional fan. 7: fluvial ridge (according to G. GIORGI, 2000).

56 The same type of evolution was described by G. GIORGI (2000) for the plain surrounding the city of Bologna. Therefore, by taking into account further investigations carried out in adjacent areas, this process could have taken place at a regional scale.

57 The plain aggradation from the Roman Age could be ascribed to different causes, such as previously occurring processes (northbound shift of the R. Po) or coeval events (climatic changes, subsidence, deforestation, abandonment of the countryside, degradation of the water flow system set up by the Romans).

58 Owing to the northbound shift of the R. Po course (D. CASTALDINI, 1989; G.B. CASTIGLIONI and G.B. PELLEGRINI, 2001), which likely started towards the end of the Bronze Age (C. BALISTA, 2003), its Apennine tributaries (among which the Rivers Secchia and Panaro) were compelled to extend their course. The effect of this extension was a decrease of the average gradient of these rivers and their tributaries, with a consequent reduction of the flow velocity and increase of sedimentation processes within the riverbeds.

59 The fall of the Roman Empire probably coincided with a deteriorating climate (A VEGGIANI, 1983), which caused the reafforestation of the Po Low Plain unit, with many channel diversions and drainage changes affecting the southern tributaries of the Po. Large areas became marshy, the plain aggraded quickly, and the centuriation tracks were often buried under fluvial and palustrine deposits (M. MARCHETTI, 2002).

60 Among the possible causes for aggradation, one could perhaps quote also the above mentioned high rate of natural subsidence which may have contributed to large sedimentary build-ups.

61 During Roman times at least 60 % of the territory had already undergone deforestation and had been turned into farming soil. Deforestation thus produced intense erosional processes and a fast aggradation of the plain (occurring also because of the climatic deterioration previously quoted) (M. MARCHETTI, 2002).

62 Man's abandonment of the countryside, which had started in the IVth century C.E. as a consequence of the political and economic decadence of that period, triggered an acceleration of the general process of riverbed build-up.

63 In the specific case of Modena (Roman Mutina), an important aggradational role could be ascribed to the abandonment of the flow-regulation hydraulic structures, the collapse of sewage networks and the degradation of the "centuriation" system following the political-economic disorders of those days (M. CREMASCHI, 2000).

64 The deep hydrographic changes which characterised Modena's urban area from the Neolithic to the Roman Age are also witnessed by recent sedimentological investigations (S. LUGLI *et al.*, 2004) which show that the Torrent Grizzaga – at present a left–hand tributary of the T. Tiepido just upstream of the confluence of the latter into the R. Panaro – used to flow across the city and continued its course further downstream.

65 After the hydrological degradation which reached its peak at the end of the VIth century C.E., following the abandonment of the territorial organisation brought about by the Romans, as witnessed by the dating of alluvial deposits found in the Modena subsoil, the morphological evolution of the study area in the Middle Ages and Modern times shows more stability, even if the area of Modena is still characterised by the risk of floods. For example, bibliographic investigations carried out for reconstructing the history of inundations in and around Modena, have identified some forty flooding events just in the XIXth and XXth centuries (IDROSER, 1988-b; L. MORATTI, 1988; PROVINCIA DI MODENA, 1996; M. CARDINALI *et al.*, 1998). These data are certainly underestimated, considering the scantiness of evidence sources.

66 In the southern part of the Modena plain the increase of human interventions along the rivers brought about a narrowing of the riverbeds, whereas intense quarrying activity led, as a consequence, to river downcutting. The deepening and related construction of check dams have modified channel morphology (they turned from a braided riverbed to a channelised course) as well as the longitudinal profile of the riverbeds (the shape of longitudinal profile changed from a hyperbola-type curve to a step-type one). Quarrying activities at the sides of the watercourses have irreversibly altered the natural morphology (D. CASTALDINI and P. BALOCCHI, 2006).

67 In the northern part of the Modena plain, the rivers' courses have been conditioned by artificial meander cut-offs.

68 Moreover, another important factor of geomorphological changes in the Modena plain has been urban development as a consequence of industrialisation. For example, the urban area of Modena has swallowed the small surrounding villages whereas many other urban areas have developed without interruption from one inhabited centre to the other.

69 In conclusion, in the Modena plain, as in other parts of the Po Plain (G.B. CASTIGLIONI and G.B. PELLEGRINI, 2001; M. MARCHETTI, 2002), the dominant geomorphic drivers switched from natural processes to processes strongly influenced by anthropogenetic activities.

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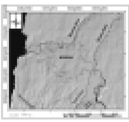	**Titre**	Figure 3 - Digital Elevation Model of the Modena plain.
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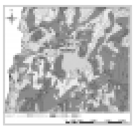	**Titre**	Figure 4 - Map of the Surface Deposits of the Modena Plain.
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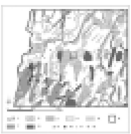	**Titre**	Figure 6 - Geoarchaeological map of the Modena Plain with fluvial forms dating from the Neolithic to the Iron Age.
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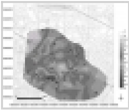	**Légende**	Black dots show evidence ascribable to the Roman soil level. Grey shades show the isobaths with 0.5 m equidistance. The deepest isobaths are represented by the darkest shades. UTM coordinates.
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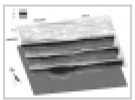	**Légende**	The 3D model includes the thickness of the following units: 1: Medieval layers; 2: alluvial deposits; 3: Roman layers. UTM coordinates.
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